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Rossby Waves in Zonally Opposing Mean Flow: Behavior in Northwest Pacific Summer Monsoon

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Abstract

The interactions between monsoon circulations and tropical disturbances in the Northwest Pacific, where the low-level mean flow is westerly in the west and easterly in the east, are studied with a barotropic model. Our model results suggest that the scale contraction by the confluent background flow, the nonlinear dynamics, the β-effect, and the large-scale convergence are important for the energy and enstrophy accumulation near the region where the zonal flow reverses. The energy/enstrophy accumulation can be maintained with a continuous Rossby wave emanation upstream. The largest accumulation occurs when the emanating zonal wavelength is around 2000 km. Longer Rossby waves experience less scale contraction and nonlinear effects while shorter Rossby waves cannot hold a coherent structure against dispersive effects.

The nonlinear energy/enstrophy accumulation mechanism is significantly different from previous linear energy accumulation theories. In the linear theories this is primarily accomplished by the slowdown of the Doppler-shifted group velocity through the convergence of mean zonal advection, while in nonlinear dynamics the contraction of the zonal wave scale plays the crucial role. More importantly, after the initial energy increase by the wave accumulation, linear dynamics will lead to an eventual loss of wave energy to the mean flow due to the increase of zonal wavenumber near the critical longitude. Thus, without the presence of other forcing processes such as diabatic heating, the disturbances will decay. In nonlinear dynamics, the sharpening of the vorticity gradient as the waves approach the confluence zone leads to the development of disturbance asymmetries with respect to the central latitude. This effect is through the nonlinear interaction of Rossby waves with the planetary vorticity gradient. This development leads to a pair of vorticity centers that straddles the central latitude with the cyclone (anticyclone) in the north (south), and an elongated, weak westerly flow along the central latitude. This elongated westerly flow, which possesses a zonal wavenumber smaller than that in the linear cases, reverses the sign of the Reynold's stress and allows the energy to grow near the critical longitude, leading to intensified disturbances.

With a more realistic monsoon-like background flow, a northwestward propagation pattern with an approximately 8-day period and 3000 km wavelength is produced, in general agreement with observed disturbances in the Northwest Pacific. The intensified disturbance may disperse energy upstream, leading to a series of trailing anticyclonic and cyclonic cells along the northwestward propagation path. When an opposing current is present, the energy dispersion leads to the formation of new disturbances in the confluence zone by a vortex axisymmetrization dynamics. Thus, our results indicate that the scale contraction and nonlinear effects may cause a succession of tropical disturbances to develop without disturbance-scale diabatic effects.